VELOCITY DISTIBUTION AT THE CROSS-OVER OF SINUSOIDAL TRAPEZOIDAL MEANDRING CHANNELS

A Thesis Submitted

In Partial Fulfilment of the Requirement for the Degree of

BACHELOR OF TECHNOLOGY

BY

PRASANTA KUMAR BAGE

Roll No-108CE044

SUDHIR KUMAR JENA

Roll No-108CE042

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTION OF TECHNOLOGY

ROURKELA

2011-2012

VELOCITY DISTIBUTION AT THE CROSS-OVER OF SINUSOIDAL TRAPEZOIDAL MEANDRING CHANNELS

A Thesis Submitted

In Partial Fulfilment of the Requirement for the Degree of

BACHELOR OF TECHNOLOGY

BY

PRASANTA KUMAR BAGE

Roll No-108CE044

SUDHIR KUMAR JENA

Roll No-108CE042

Under The Guidance Of

Prof.K.K.Khatua

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTION OF TECHNOLOGY

ROURKELA

2011-2012

CERTIFICATE

This is to certify that the project entitled ***Velocity distribution at the cross-over of sinusoidal trapezoidal meandering channels*** submitted by Mr. ***Prasanta Kumar Bage*** (Roll No. **108CE044)** and Mr. ***Sudhir Kumar Jena*** (Roll. No.**108CE042**) in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at NIT Rourkela is an authentic work carried out by him under my supervision and guidance.

Date-

Prof. K.K.Khatua
Dept. of Civil Engineering
NIT Rourkela

ACKNOWLEDGEMENT

We would like to thank **NIT Rourkela** for giving us the opportunity to use their resources and work in such a challenging environment.

First and foremost we take this opportunity to express our deepest sense of gratitude to our guide ***Prof.K.K.Khatua*** for his able guidance during our project work. This project would not have been possible without his help and the valuable time that he has given us from his busy schedule.

We would also like to extend our gratitude to ***Prof. N. Roy,*** *Head, Department of Civil Engineering,* who has always encouraged and supported doing our work.

We are also thankful to Mr. P.K. Mohanty, Mr. Rout and Research Scholar, of Water Resource Engineering and staff members of the **Water Resource Engineering Laboratory,** for helping and guiding us during the experiments.

PRASANTA KUMAR BAGE
108CE044
SUDHIR KUMAR JENA
108CE042

ABSTRACT

Evaluation of velocity distribution process longitudinally is very much essential for the environmental management, quantifying the mean velocity. In nature, most rivers tend to be of compound sections as well as meandering [1]. Velocity distribution is crucial for solving many engineering problems such as management of rivers and floodplains, it is important to understand the behaviours of flows within compound channels for designing of hydraulic structure, flood control, water management, sedimentation and excavation. During flood runoff water comes out natural or man-made channel, part of the discharge is carried out by simple main channel rest are carried out by flood plain. Experiment results are presented here for the studies conducted in two self designed channels, developed by known discharge. These data's were used for the analysis of velocity distribution and depth average. Velocity at the cross-over of a meandering channel of different sinuosity at various flow depth where investigated for monitoring the contour mapping of flow and graphical analysis of velocity at the cross-over.

Keywords

- Meandering channel;
- Velocity Distribution;
- Open channel flow;
- Velocity pattern;
- Compound Channel

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER-1

INTRODUCTION:

1.1 Open Channel Flow

Flow of a liquid with a free surface is termed as open channel flow. A free surface is the one having constant pressure such as atmospheric pressure. In case of open channel flow, as the pressure is atmospheric, the flow takes place under the force of gravity which means the flow takes place due to the slope of the bed of the channel only

1.2 Classification of Flows in Channel

i. Steady flow and unsteady flow.
ii. Uniform flow and non-uniform flow.
iii. Laminar flow and turbulent flow.
iv. Sub-critical, critical and super critical flow.

Steady Flow and Unsteady Flow

If the flow characteristics such as depth of flow, velocity of flow, rate of flow at any point in open channel flow do not change with respect to time, the flow is said to be steady flow whereas if at any point in open channel flow, the velocity of flow, depth of flow or rate of flow changes with respect to time, is said to be unsteady flow.

Uniform Flow and Non-uniform Flow

If for a given length of the channel, the velocity of flow, depth of flow, slope of the channel and cross-section remain constant, the flow is said to be uniform whereas if for a given length of the channel, the velocity of flow, depth of flow etc., do not remain constant, the flow is said to be non-uniform flow.

Laminar Flow and Turbulent Flow

The flow in open channel is said to be laminar if Reynold number (R_e) is less than 500 or 600 and if the Reynold number is more than 2000, the flow is said to be turbulent in open channel flow. If R_e lies between 500 to 2000, the flow is considered to be in transition state.

Sub-critical, Critical and Super Critical Flow

The flow in open channel is said to be sub-critical if the Froude number (F_e) is than 1.0. The flow is called critical if $\mathbf{F_e = 1.0}$ and if $\mathbf{F_e > 1.0}$, the flow is called sinusoidal.

per critical or shooting or rapid or torrential.

Froude number is defined as :

$$F_e = V/(gD)^{1/2} \qquad \textbf{...(1.1)}$$

Where .

V = Mean velocity of flow

D = Hydraulic depth of channel = A/T

A=Wetted area

T=Top width of channel

1.3 Compound channel flow

Compound channel consist of main channel and flood plain. When the flow in the natural or main made channel exceeds the channel section, flow of water take place in the flood plain . The can result to sever damage to the life and property.

There is a variation in the velocity in the main channel and flood because a various reasons. Boundary shear is quite high in the flood plan then comparing to the main channel. There are rest main factors which contribute to the resistance of flow.

Fig.1 below shows the schematic diagram of a compound channel flow includes meandering channel as main channel and flood plain.

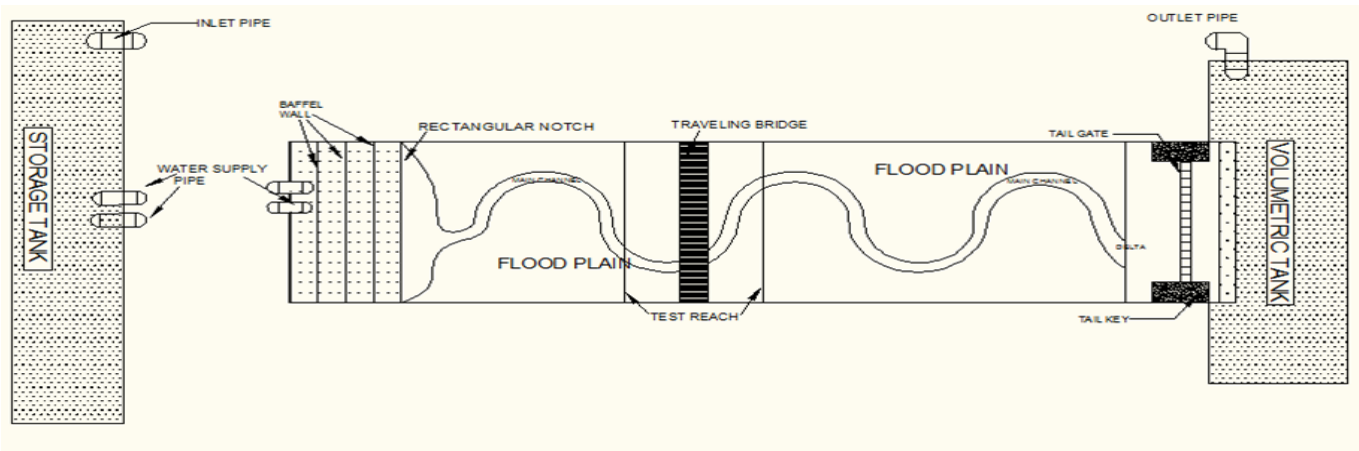


Fig.1 schematic diagram shows the experimental set-up

A meandering stream follows a sinuous path as shown in fig .2 below. This stream type can be described by quantifying the various parameters defining its geometry.

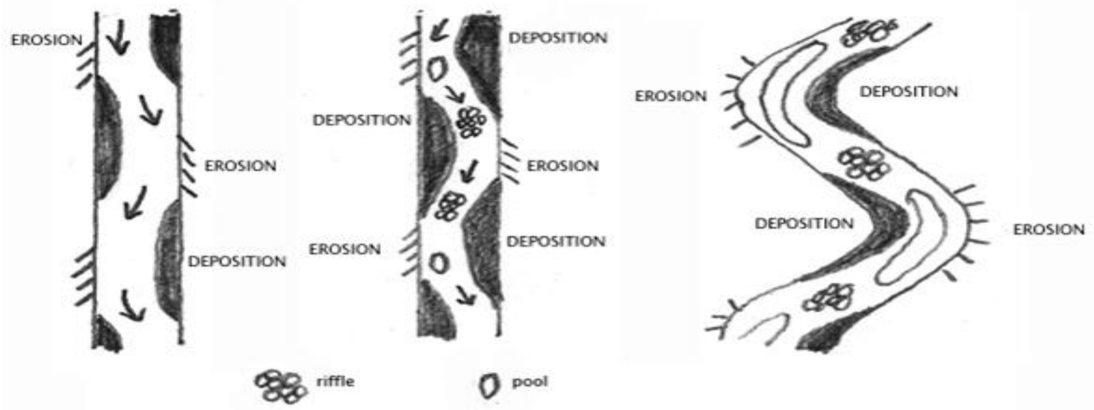


Fig.2 straight channel leads to meandering channel

Various parameters of meandering channels are:-

(a) Meander wavelength

(b) Meander width

(c) Channel width

(d) Channel depth

(e) Bend radius

(f) Sinuosity

The region between two consecutive meander bends is known as the cross-over region. A meandering channel has straight reaches in the crossover region and curved reaches in the bend apex region.

The extent of meandering in a river is often expressed by calculating its sinuosity. The sinuosity of meandering rivers is defined as the ratio between the length of the river measured along its thalweg (line of maximum depth) and the valley length between the upstream and downstream sections[Rust, 1978] :-

$$S = L_T/L_O \qquad \textbf{…(1.2)}$$

S= Sinuosity; L_T= Distance between the start and end point of the considered river reach computed along the thalweg ;

L_O= The valley length between the same start and end point

CHAPTER-2

LITERATURE REVIEW

Studies over meandering and straight channels were started long back. First investigation was done by Thomas (1876) after than lots of laboratory works, studies and research work has been done. Thomas observed the existence spiral motion curved region of open channel. It is very much essential to know the property of flow in the simple and compound channel flow. Study of meandering channel is more complex than straight channel. Geometry of compound channel is similar to that sin curve. The depth of curve is measured with its sinuosity. Higher is the sinuosity more is the curve.

Yee-Chung Jin, Y.Zheng , and A.R. Zarrati(2004) made the semi analytic model to predict boundary shear distribution in a straight, non-circular duct and open channels. This model was used to simplify stream wise velocity equation, which involves only secondary reynolds stress terms.

J.B. Boxall, I. Guyme(2007) reported the experiment data in three self-formed channels, where the discharge was known . Investigation of flow and longitudinal mixing at various flow rates within each of the channels by conducting the development of trace plumes through the channels. Coefficients required for solution of the one-dimensional advection dispersion equation (1D-ADE) were found in the range 0.02–0.2m s, using an optimisation procedure.

Kyle M. Straub ,David Mohrig, James Buttles, Brandon McElroy, and Carlos Pirmez (2011) they did the laboratory experiments that highlight the effect of channel sinuosity on the depositional mechanics. Three experimental channels of different sinuosity but similar in cross-sectional geometry was filled with water observed current properties and the evolution of topography via sedimentation. The experiments are used to force the run-up of channelized turbidity currents on the outer banks of moderate to high curvature channel bends.

Xiaonan Tang, Donald W. Knight(2008) This paper reviews a model, developed by Shiono and Knight [Shiono K, Knight DW. Two-dimensional analytical solution for a compound channel. In: Proceedings of the 3rd international symposium on refined flow modelling and turbulence measurements, Tokyo,Japan, July 1988. p. 503–10; Shiono K, Knight DW. Turbulent open channel flows with variable depth across the channel. J Fluid Mech1991; 222:617–46 [231:693]], which gave the analytical solutions to Navier–Stokes equations, and includes the effect on the bed due to friction, and secondary flows. Comparing the two new analytical solutions are it is compared with the conventional solution for one trapezoidal compound channel and three simple channel to highlight their deference's and the importance of the secondary flow and plan form vorticity term. Analytical results were compared with the experimental data to show that the general SKM predicts the lateral distributions of depth-averaged velocity well.

Kishanjit Kumar Khatua and Kanhu Charan Patra: Investigation for the shear stress distribution in the main channel and floodplain of meandering and straight compound channels are presented. This paper predicts the distribution of boundary shear carried by main channel and floodplain, based on the experimental results of boundary shear. Five dimensionless parameters are used to form equations representing the total shear force percentage carried by floodplains. A set of smooth and rough sections is studied with aspect ratio varying from 2 to 5. The models are also validated using the data of other investigators.

CHAPTER-3

Experimental

3.1 Experimental Set-up

Experiment was carried out in different trapezoidal meandering channel (Fig. 3) of different sinuosity i.e. 1.2 and 1.5. The sinuosity of meandering rivers is defined as the ratio between the length of the river measured along its *thalweg* (line of maximum depth) and the valley length between the upstream and downstream sections[Rust, 1978] :-

$$S = L_T/L_O \qquad \textbf{...(3.1)}$$

Where,

S= Sinuosity,

L_T= Distance between the start and end point of the considered river reach computed along the *thalweg* ;

L_O= The valley length between the same start and end point

Before starting the experiment these channels where build over a rectangular flume of 20 meter long and 4 meter wide. The plan geometry of these channels was designed using sine curve which has been shown to reproduce the shape of main sub aerial channels.

This curve describes the local direction of the channel, to the direction of stream flow:

$$\varphi = \omega \cos(2\pi s/ M) \qquad \ldots(3.2)$$

where,

φ = angle of meander path with the mean longitudinal axis (degrees or radians)

ω = maximum angle a path makes with the mean longitudinal axis(degrees or radians)

s = curvilinear coordinate along the meander path (ft or m)

M = meander arc length (ft or m)

The cross-section for these channels were trapezoidal in shape and the depth of channels was taken 6.5cm. Most of the river flowing in the north, west and southern part of India have very mild slope. Taking the similar characteristics of these rivers initial bed slopes was taken .002 or 2:1000. The slope taken was found to be very small which comes under mild slope zone.

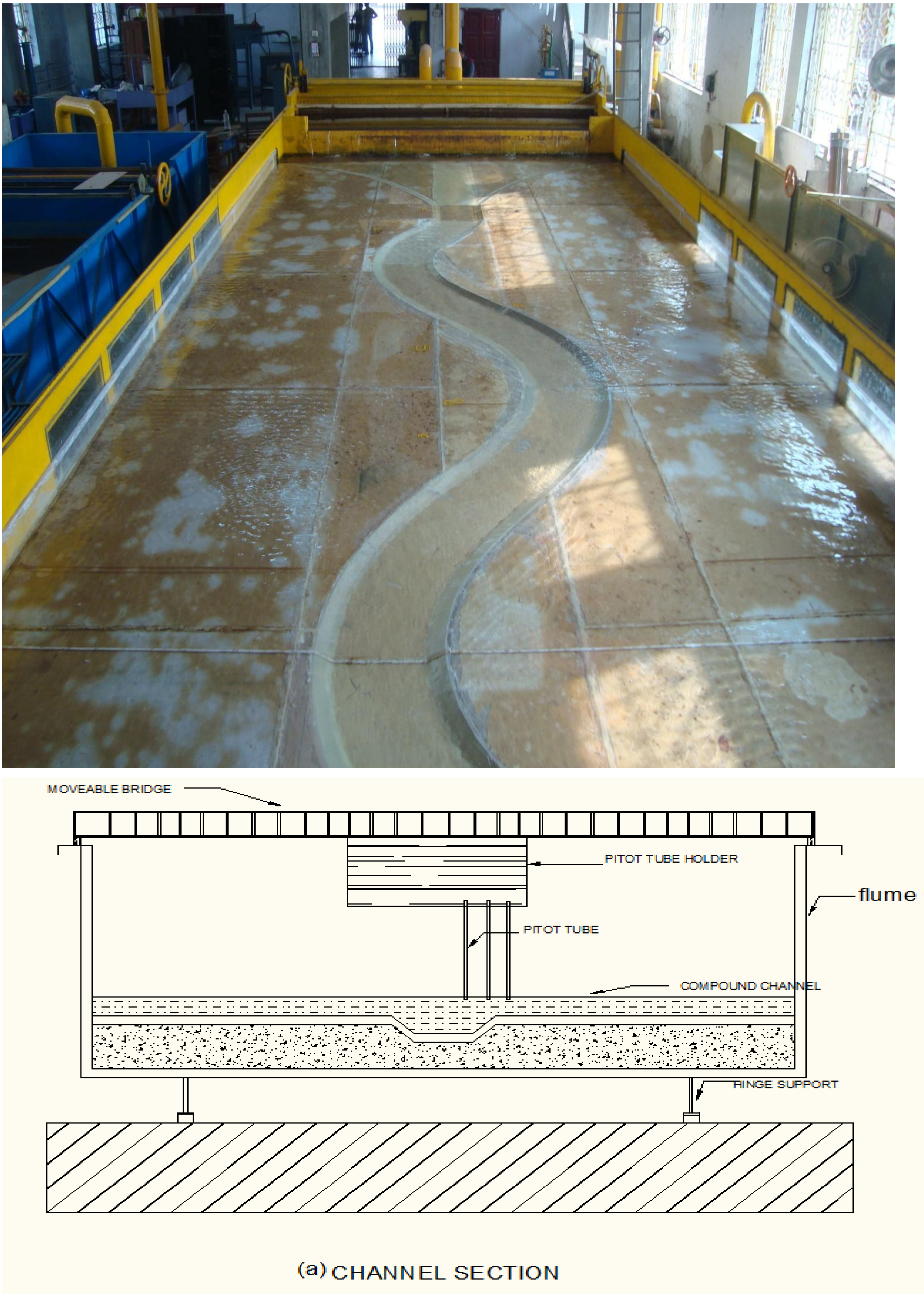


Fig.3 Upstream view of the trapezoidal meandering channel

3.2 Experimental Procedure

3.2.1 Design of the working channel

The working channels were designed on the basis of the properties of rivers flowing in the north, west and southern parts of India.

The following design formulas were considered for the designing of the two meandering channels we worked upon.

DESIGN FORMULAS FOR CHANNEL FLOW

Manning's formula (Chow, 1959)

$$V=(R^{2/3}S^{1/2}/n) \qquad \text{…(3.3)}$$

where ,

v = average velocity, m/sec

R =(A/P)= hydraulic radius, m

A = cross-sectional area of the channel, m^2

P_w = wetted perimeter of the channel, m

S = slope of the channel

n = roughness coefficient

The values of n for various channel conditions are illustrated in Table 2.

Discharge formula

$$Q=V \times A =(A*R^{2/3}S^{1/2}/n) \text{ , } m^3/sec \qquad \text{…(3.4)}$$

Normal water depth formula

$$h = [(b/2Z)^{2} +A/Z]^{1/2} – b/2Z \text{ , m} \qquad \text{…(3.5)}$$

Slope formula

$$S = (n*v/R^{2/3})^{½} \qquad \textbf{…(3.6)}$$

Where,

b = bottom width of the channel, m

z = ratio of the side slope

Table.1 Values of the Roughness Coefficient n (Simon, 1976)

Channel condition	**Value of n**
Exceptionally smooth, straight surfaces: enamelled or glazed coating; glass; lucite; brass	0.009
Very well planed and fitted boards; smooth metal; pure cement plaster; smooth tar or paint coating	0.010
Planed lumber; smoothed mortar (1/3 sand) without projections, in straight alignment	0.011
Carefully fitted but unplaned boards, steel trowelled concrete in straight alignment	0.012
Reasonably straight, clean, smooth surfaces without projections; good boards; carefully built brick wall; wood trowelled concrete; smooth, dressed ashlar	0.013
Good wood, metal, or concrete surfaces with some curvature, very small projections, slight moss or algae growth or gravel deposition. Shot concrete surfaced with trowelled mortar	0.014
Rough brick; medium quality cut stone surface; wood with algae or moss growth; rough concrete; riveted steel	0.015
Very smooth and straight earth channels, free from growth; stone rubble set in cement; shot, untrowelled concrete deteriorated brick wall; exceptionally well excavated and surfaced channel cut in natural rock	0.017
Well-built earth channels covered with thick, uniform silt deposits; metal flumes with excessive curvature, large projections, accumulated debris	0.018

Smooth, well-packed earth; rough stone walls; channels excavated in solid, soft rock; little curving channels in solid loess, gravel or clay, with silt deposits, free from growth, in average condition; deteriorating uneven metal flume with curvatures and debris; very large canals in good condition	0.020
Small, manmade earth channels in well-kept condition; straight natural streams with rather clean, uniform bottom without pools and flow barriers, cavings and scours of the banks	0.025
Ditches; below average manmade channels with scattered cobbles in bed	0.028
Well-maintained large floodway; unkempt artificial channels with scours, slides, considerable aquatic growth; natural stream with good alignment and fairly constant cross-section	0.030
Permanent alluvial rivers with moderate changes in cross-section, average stage; slightly curving intermittent streams in very good condition	0.033
Small, deteriorated artificial channels, half choked with aquatic growth, winding river with clean bed, but with pools and shallows	0.035
Irregularly curving permanent alluvial stream with smooth bed; straight natural channels with uneven bottom, sand bars, dunes, few rocks and underwater ditches; lower section of mountainous streams with well-developed channel with sediment deposits; intermittent streams in good condition; rather deteriorated artificial channels, with moss and reeds, rocks, scours and slides	0.040
Artificial earth channels partially obstructed with debris, roots, and weeds; irregularly meandering rivers with partly grown-in or rocky bed; developed flood plains with high grass and bushes	0.067
Mountain ravines; fully ingrown small artificial channels; flat flood plains crossed by deep ditches (slow flow)	0.080
Mountain creeks with waterfalls and steep ravines; very irregular flood plains; weedy and sluggish natural channels obstructed with trees	0-10
Very rough mountain creeks, swampy, heavily vegetated rivers with logs and driftwood on the bottom; flood plain forest with pools	0.133
Mudflows; very dense flood plain forests; watershed slopes	0.22

Table 2 Allowable Mean Velocities against Erosion or Scour in Channels of various Soils

Description	v, m/sec
Soft clay or very fine clay	0-2
Very fine or very light pure sand	0.3
Very light loose sand or silt	0.4
Coarse sand or light sandy soil	0.5
Average sandy soil and good loam	0.7
Sandy loam	0.8
Average loam or alluvial soil	0.9
Firm loam, clay loam	1.0
Firm gravel or clay	1.1
Stiff clay soil; ordinary gravel soil, or clay and gravel	1.4
Broken stone and clay	1.5
Grass	1.2
Coarse gravel, cobbles, shale	1.8
Conglomerates, cemented gravel, soft slate, tough hardpan, soft sedimentary rock	1.8 – 2.5
Soft rock	1.4 - 2.5
Hard rock	3.0 - 4.6
Very hard rock or cement concrete (1:2:4 minimum)	4.6 - 7.6

Table 3 Allowable Side Slopes for Trapezoidal Channels in various Soils (Davis, 1952)

Type of soil	Z
Light sand, wet clay	3:1
Wet sand	2.5:1
Loose earth, loose sandy loam	2:1
Ordinary earth, soft clay, sandy loam, gravelly loam or loam	1.5:1
Ordinary gravel	1.25:1
Stiff earth or clay, soft moorum	1:1

Tough hard pan, alluvial soil, firm gravel, hard compact earth, hard moorum	0.5:1
Soft rock	0.25:1

3.2.2 Calibration of the notch

- Measurement of water surface elevation in the collecting tank after discharge was measured with the point gauge with accuracy of 0.1 cm.
- Depending on the discharge and height above the notch at intervals of 30 sec, change in the water level in the collecting tank for that particular time was noted.
- Volume of water collected was compared with the actual discharge.
- Coefficient of discharge (C_d) was then obtained from the ratio of the actual discharge to the theoretical discharge.
- C_d generally varies between 0.6 to 0.8.

$$Q_t = (2/3)\, C_d\, (2g)^{½}\, L\, H^{3/2} \qquad \textbf{...(3.7)}$$

Time, t=30 sec

Table.4. Calculation of coefficient of discharge

Sl. No.	**Q_a, (m)**	**Q_t ,(m)**	**C_d**
1	0.0269	0.0338	0.7958
2	0.0387	0.0507	0.7633
3	0.0364	0.0546	0.666
4	0.0570	0.0786	0.725

Average C_d = 0.7

3.2.2 Measurement of in pressure differences

A pitot-tube is a device used for measuring the velocity of flow at any point in a pipe or a channel as shown in the fig.4. It is based on the principle that if the velocity of flow at a point becomes zero, the pressure there is increased due to the conversion of kinetic energy into pressure energy.

In its simplest form, the Pitot-tube consists of a steel tube bent at right angle. The lower end, which is bent through 90^0 is directed in the upstream direction of the water. The liquid rises up in the tube due to the conversion of kinetic energy to pressure energy. The velocity is determined by measuring the rise of liquid in the tube.

The theoretical velocity is given by:

$$V_{th} = (2gh)^{1/2} \qquad \textbf{…(3.8)}$$

Where'

h = difference of pressure head

The actual velocity is given by:

$$V = C_v(2gh)^{1/2} \qquad \textbf{…(3.9)}$$

Where,

C_v = coefficient of pitot-tube

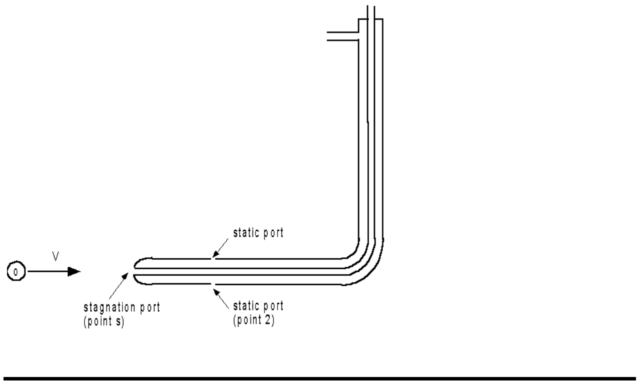


Fig.4 Pitot-Tube

Pressure difference at various location in a meandering channel for different depth and sinuosity of channel was recorded. A set of five Pitot- tube placed at a distance of 4cm was used to record the pressure difference at different location in the main channel and in the flood plain for various depths of flow in the meandering channel. Instrumental set-up can be seen in the figure above.

The data recorded was used for the further calculation of velocity which was executed through the contour diagram for the analysis of velocity distribution.

3.2.3 Experimental data

<u>Sinuosity 1.25</u>

Table.5. Calculation of Velocity for 3.27cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/1000**	**X AXIS**	**Y AXIS**	**VELOCITY $(2*gh)^{½}$,(m/s)**
-25	-27	0.002	7.5	1.2385	0.2
-25	-27.5	0.0025	8	1.2385	0.223607
-28	-30	0.002	12	1.2385	0.2
-28	-29.5	0.0015	16	1.2385	0.173205
-27	-29	0.002	20	1.2385	0.2
-29.5	-31	0.0015	24	1.2385	0.173205
-27	-29	0.002	28	1.2385	0.2
-27.5	-29	0.0015	32	1.2385	0.173205
-30	-31	0.001	36	1.2385	0.141421
-30	-31	0.001	40	1.2385	0.141421
-31	-32	0.001	40.5	1.2385	0.141421
-26.5	-27.5	0.001	6.192	2.5465	0.141421
-26	-28	0.002	7.5	2.5465	0.2
-26	-29	0.003	8	2.5465	0.244949
-25	-28	0.003	12	2.5465	0.244949
-28	-30	0.002	16	2.5465	0.2
-27	-30	0.003	20	2.5465	0.244949

-29	-32	0.003	24	2.5465	0.244949
-27	-29.5	0.0025	28	2.5465	0.223607
-26.5	-30	0.0035	32	2.5465	0.264575
-29.5	-31.5	0.002	36	2.5465	0.2
-30	-31	0.001	40	2.5465	0.141421
-30.5	-31.5	0.001	40.5	2.5465	0.141421
-31	-32	0.001	41.808	2.5465	0.141421
28.5	28	0.0005	4.884	3.8545	0.1
28.5	26.5	0.002	7.5	3.8545	0.2
29	25.5	0.0035	8	3.8545	0.264575
31	27.5	0.0035	12	3.8545	0.264575
31	27.5	0.0035	16	3.8545	0.264575
30	26	0.004	20	3.8545	0.282843
32	29.5	0.0025	24	3.8545	0.223607
31	27	0.004	28	3.8545	0.282843
30	26.5	0.0035	32	3.8545	0.264575
32	30	0.002	36	3.8545	0.2
32	31	0.001	40	3.8545	0.141421
31.5	30.5	0.001	40.5	3.8545	0.141421
31.5	31	0.0005	43.116	3.8545	0.1

Table.6 Calculation of Velocity for 6.08cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/1000**	**X AXIS**	**Y AXIS**	**VELOCITY $(2*gh)^{½}$,(m/s)**
4	0	0.004	7.5	1.2385	0.282843
4	-1	0.005	8	1.2385	0.316228
2.5	-2.5	0.005	12	1.2385	0.316228
4	-1	0.005	16	1.2385	0.316228
-1.5	-3.5	0.002	20	1.2385	0.2

1.5	-3	0.0045	24	1.2385	0.3
4	1	0.003	28	1.2385	0.244949
4	-0.5	0.0045	32	1.2385	0.3
4	-2.5	0.0065	36	1.2385	0.360555
0.5	-3	0.0035	40	1.2385	0.264575
0.5	-3.5	0.004	40.5	1.2385	0.282843
3	1	0.002	5.064	3.438385	0.2
5	1	0.004	7.5	3.438385	0.282843
6	1.5	0.0045	8	3.438385	0.3
4.5	-2.5	0.007	12	3.438385	0.374166
5	-1	0.006	16	3.438385	0.34641
6.5	-1.5	0.008	20	3.438385	0.4
4	-3	0.007	24	3.438385	0.374166
6	-0.5	0.0065	28	3.438385	0.360555
7	-1	0.008	32	3.438385	0.4
4	-2	0.006	36	3.438385	0.34641
3	-2.5	0.0055	40	3.438385	0.331662
2.5	-3	0.0055	40.5	3.438385	0.331662
-4	-5	0.001	42.936	3.438385	0.141421
3.5	1	0.0025	2.628	5.874385	0.223607
6.5	2	0.0045	7.5	5.874385	0.3
7	2	0.005	8	5.874385	0.316228
6.5	2.5	0.004	12	5.874385	0.282843
7.5	0	0.0075	16	5.874385	0.387298
7	-1	0.008	20	5.874385	0.4
4.5	-3.5	0.008	24	5.874385	0.4
5.5	-2	0.0075	28	5.874385	0.387298
7.5	-1	0.0085	32	5.874385	0.412311
1.5	-3.5	0.005	36	5.874385	0.316228
0.5	-4	0.0045	40	5.874385	0.3
1	-4	0.005	40.5	5.874385	0.316228
-2	-3.5	0.0015	45.372	5.874385	0.173205

Table.7 Calculation of Velocity for 8.265cm Depth of Flow

DYNAMIC PRESSURE (D)	STATIC PRESSURE (S)	DIFFERENCE (S-D)/1000	X AXIS	Y AXIS	VELOCITY $(2*gh)^{1/2}$,(m/s)
23	21.5	0.0015	7.5	1.2385	0.173205
22.5	21	0.0015	8	1.2385	0.173205
21	19.5	0.0015	12	1.2385	0.173205
22	19	0.003	16	1.2385	0.244949
22.5	21	0.0015	20	1.2385	0.173205
19.5	18	0.0015	24	1.2385	0.173205
22	19	0.003	28	1.2385	0.244949
23	21.5	0.0015	32	1.2385	0.173205
19.5	18	0.0015	36	1.2385	0.173205
19	15	0.004	40	1.2385	0.282843
18.5	17	0.0015	40.5	1.2385	0.173205
23.5	22	0.0015	5.064	3.438385	0.173205
23.5	21.5	0.002	7.5	3.438385	0.2
24	21	0.003	8	3.438385	0.244949
23	17.5	0.0055	12	3.438385	0.331662
23.5	19.5	0.004	16	3.438385	0.282843
23	17.5	0.0055	20	3.438385	0.331662
20	14.5	0.0055	24	3.438385	0.331662
23	17.5	0.0055	28	3.438385	0.331662
22.5	19	0.0035	32	3.438385	0.264575
19.5	14	0.0055	36	3.438385	0.331662
19.5	15.5	0.004	40	3.438385	0.282843
20.5	19	0.0015	40.5	3.438385	0.173205
20	18.5	0.0015	42.936	3.438385	0.173205
23.5	22	0.0015	2.628	5.874385	0.173205
24.5	21	0.0035	7.5	5.874385	0.264575

25	19.5	0.0055	8	5.874385	0.331662
23	17.5	0.0055	12	5.874385	0.331662
24	18.5	0.0055	16	5.874385	0.331662
22.5	20	0.0025	20	5.874385	0.223607
19	13.5	0.0055	24	5.874385	0.331662
23	19.5	0.0035	28	5.874385	0.264575
22	16.5	0.0055	32	5.874385	0.331662
19	15.5	0.0035	36	5.874385	0.264575
19	16	0.003	40	5.874385	0.244949
19.5	16	0.0035	40.5	5.874385	0.264575
19	16.5	0.0025	45.372	5.874385	0.223607
22	20.5	0.0015	0	7.5	0.173205081
19	17.5	0.0015	-8	7.5	0.173205081
13	11.5	0.002	-16	7.5	0.2
18	17	0.001	-24	7.5	0.141421356
21	19	0.001	47	7.5	0.141421356
17	15.5	0.0015	55	7.5	0.173205081
18	16	0.002	63	7.5	0.2
23	21.5	0.0015	71	7.5	0.173205081

Table.8 Calculation of Velocity for 9.9cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/1000**	**X AXIS**	**Y AXIS**	**VELOCITY $(2*gh)^{½}$,(m/s)**
44.5	41	0.0035	7.5	1.2385	0.264575
45	40.5	0.0045	8	1.2385	0.3
42	39.5	0.0025	12	1.2385	0.223607
44.5	42	0.0025	16	1.2385	0.223607

46	43.5	0.0025	20	1.2385	0.223607
41.5	38	0.0035	24	1.2385	0.264575
45.5	42	0.0035	28	1.2385	0.264575
45	41.5	0.0035	32	1.2385	0.264575
41	37.5	0.0035	36	1.2385	0.264575
39.5	37	0.0025	40	1.2385	0.223607
39	35	0.004	40.5	1.2385	0.282843
42	38	0.004	5.52	3.9985	0.282843
41	35	0.006	7.5	3.2185	0.34641
44	39	0.005	8	3.2185	0.316228
41	35	0.006	12	3.2185	0.34641
45	36	0.009	16	3.2185	0.424264
45	39	0.006	20	3.2185	0.34641
40	32	0.008	24	3.2185	0.4
46	37	0.009	28	3.2185	0.424264
43	38	0.005	32	3.2185	0.316228
41	32	0.009	36	3.2185	0.424264
41	33	0.008	40	3.2185	0.4
40	33	0.007	40.5	3.2185	0.374166
39	36.5	0.0025	42.48	3.2185	0.223607
43	39	0.004	3.5	5.2385	0.282843
46	39	0.007	7.5	5.2385	0.374166
47	39	0.008	8	5.2385	0.4
43	34	0.009	12	5.2385	0.424264
44	36	0.008	16	5.2385	0.4
41	32	0.009	20	5.2385	0.424264
38	32	0.006	24	5.2385	0.34641
43	34	0.009	28	5.2385	0.424264
41	32	0.009	32	5.2385	0.424264
40	33	0.007	36	5.2385	0.374166
41	33	0.008	40	5.2385	0.4
41	34	0.007	40.5	5.2385	0.374166

39	36.5	0.0025	44.5	5.2385	0.223607
39	38	0.001	1.5	7.2385	0.141421
41	39	0.002	7.5	7.2385	0.2
41	28	0.013	8	7.2385	0.509902
42	35	0.007	12	7.2385	0.374166
45	36	0.009	16	7.2385	0.424264
40	27	0.013	20	7.2385	0.509902
37	28	0.009	24	7.2385	0.424264
41	36	0.005	28	7.2385	0.316228
39	35	0.004	32	7.2385	0.282843
37	24	0.013	36	7.2385	0.509902
37	28	0.009	40	7.2385	0.424264
38	33	0.005	40.5	7.2385	0.316228
38	34	0.004	46.5	7.2385	0.282843
40	36	0.004	1	7.5	0.282843
37	31	0.006	-7	7.5	0.34641
41	38.5	0.0025	47	7.5	0.223607
39	34	0.005	55	7.5	0.244949
37	33	0.004	1	9	0.282843
37	34	0.003	-7	9	0.360555
38	35.5	0.0025	47	9	0.223607

Table.9 Calculation of Velocity for 9.395cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/1000**	**X AXIS**	**Y AXIS**	**VELOCITY (2*gh) ^{½},(m/s)**
37	36	1	7.5	1.2385	0.141421
37	33.5	3.5	8	1.2385	0.264575
34.5	33.5	1	12	1.2385	0.141421
36	32	4	16	1.2385	0.282843
37	36	1	20	1.2385	0.141421

34	33	1	24	1.2385	0.141421
36	35	1	28	1.2385	0.141421
37.5	34	3.5	32	1.2385	0.264575
33	32	1	36	1.2385	0.141421
33	29.5	3.5	40	1.2385	0.264575
32.5	29	3.5	40.5	1.2385	0.264575
37	33.5	3.5	3.74	4.9985	0.264575
37.5	33.5	4	7.5	4.9985	0.282843
37.5	34.5	3	8	4.9985	0.244949
35.5	32	3.5	12	4.9985	0.264575
37	32.5	4.5	16	4.9985	0.3
38	34.5	3.5	20	4.9985	0.264575
33	29.5	3.5	24	4.9985	0.264575
37	32	5	28	4.9985	0.316228
36.5	31.5	5	32	4.9985	0.316228
33.5	26.5	7	36	4.9985	0.374166
35	27.5	7.5	40	4.9985	0.387298
35	31.5	3.5	40.5	4.9985	0.264575
34	30.5	3.5	44.26	4.9985	0.264575
37.5	34	3.5	1.86	6.8785	0.264575
37.5	33.5	4	7.5	6.8785	0.282843
38	30	8	8	6.8785	0.4
36.5	30	6.5	12	6.8785	0.360555
37.5	32.5	5	16	6.8785	0.316228
39	32.5	6.5	20	6.8785	0.360555
32.5	28	4.5	24	6.8785	0.3
38.5	32.5	6	28	6.8785	0.34641
36.5	31	5.5	32	6.8785	0.331662
34	28	6	36	6.8785	0.34641
35	27.5	7.5	40	6.8785	0.387298
35	28	7	40.5	6.8785	0.374166
32.5	29	3.5	46.14	6.8785	0.264575

34	30.5	3.5	1	8.7385	0.264575
37.5	34	3.5	7.5	8.7385	0.264575
38	30	8	8	8.7385	0.4
36.5	30	6.5	12	8.7385	0.360555
37.5	33	4.5	16	8.7385	0.3
39.5	32	7.5	20	8.7385	0.387298
31	23	8	24	8.7385	0.4
39	33	6	28	8.7385	0.34641
34.5	27	7.5	32	8.7385	0.387298
28.5	26	2.5	36	8.7385	0.387298
29	27	2	40	8.7385	0.2
29.5	27.5	2	40.5	8.7385	0.2
29	28	1	47	8.7385	0.141421
34	30.5	3.5	1	7.5	0.264575
37.5	33	3.5	-7	7.5	0.264575
38	35	3	47	7.5	0.244949
36.5	33.5	3	55	7.5	0.244949
37.5	30.5	7	1	8.5	0.374166
39.5	33.5	6	-7	8.5	0.34641
31	26	5	47	8.5	0.316228
31	27	4	55	8.5	0.282843

Sinuosity 1.5

Table.10 Calculation of Velocity for 2.8cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/1000**	**X AXIS**	**Y AXIS**	**VELOCITY $(2*gh)^{1/2}$,(m/s)**
40	39.5	0.005	6.5	1.2385	0.316228
40.5	40	0.005	7	1.2385	0.316228
44	43.5	0.005	11	1.2385	0.316228
43	42.5	0.005	15	1.2385	0.316228
43	42.5	0.005	19	1.2385	0.316228
42	41	0.01	23	1.2385	0.447214
42.5	41.5	0.01	27	1.2385	0.447214
40	39	0.01	31	1.2385	0.447214
46	45.5	0.005	35	1.2385	0.316228
40	39.5	0.005	39	1.2385	0.316228
40	39.5	0.005	39.5	1.2385	0.316228
40.5	40	0.005	5.5	2.2385	0.316228
40.5	40	0.005	6.5	2.2385	0.316228
40.5	37	0.035	7	2.2385	0.83666
44	41.5	0.025	11	2.2385	0.707107
43	41.5	0.015	15	2.2385	0.547723
43	41.5	0.015	19	2.2385	0.547723
42.5	41	0.015	23	2.2385	0.547723
42	40	0.02	27	2.2385	0.632456
46	43.5	0.025	31	2.2385	0.707107
45.5	43	0.025	35	2.2385	0.707107
46	45.5	0.005	39	2.2385	0.316228
46	45.5	0.005	39.5	2.2385	0.316228
46	45.5	0.005	40.5	2.2385	0.316228
41	40	0.01	4.8	2.9385	0.447214
41	39.5	0.015	6.5	2.9385	0.547723

41	39	0.02	7	2.9385	0.632456
44	41.5	0.025	11	2.9385	0.707107
43.5	41	0.025	15	2.9385	0.707107
43	41	0.02	19	2.9385	0.632456
42.5	40	0.025	23	2.9385	0.707107
42	40	0.02	27	2.9385	0.632456
46	43	0.03	31	2.9385	0.774597
45.5	42	0.035	35	2.9385	0.83666
45.5	42	0.035	39	2.9385	0.83666
45.5	43	0.025	39.5	2.9385	0.707107
45.5	45	0.005	41.2	2.9385	0.316228

Table11. Calculation of Velocity for 3.28cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/1000**	**X AXIS**	**Y AXIS**	**VELOCITY $(2*gh)^{½}$,(m/s)**
34	32	0.02	6.5	1.2385	0.632456
34	31.5	0.025	7	1.2385	0.707107
37.5	34.5	0.03	11	1.2385	0.774597
36.5	34	0.025	15	1.2385	0.707107
36.5	34.5	0.02	19	1.2385	0.632456
36	34	0.02	23	1.2385	0.632456
36	34.5	0.015	27	1.2385	0.547723
39	37	0.02	31	1.2385	0.632456
39	37.5	0.015	35	1.2385	0.547723
39	38	0.01	39	1.2385	0.447214
39	38.5	0.005	39.5	1.2385	0.316228
38.5	37	0.015	5	2.7385	0.547723
34	31.5	0.025	6.5	2.7385	0.707107
34	31	0.03	7	2.7385	0.774597

38.5	33.5	0.05	11	2.7385	1
37.5	33.5	0.04	15	2.7385	0.894427
36.5	33	0.035	19	2.7385	0.83666
36	33.5	0.025	23	2.7385	0.707107
36	33	0.03	27	2.7385	0.774597
39	36.5	0.025	31	2.7385	0.69282
39	37	0.02	35	2.7385	0.632456
39	38	0.01	39	2.7385	0.447214
39	38.5	0.005	39.5	2.7385	0.316228
39	38.5	0.005	41	2.7385	0.316228
34.5	32	0.025	4	3.7385	0.707107
34.5	31.5	0.03	6.5	3.7385	0.774597
34	31.5	0.025	7	3.7385	0.707107
38	33	0.05	11	3.7385	1
36.5	33	0.035	15	3.7385	0.83666
36	33	0.03	19	3.7385	0.774597
35	33	0.02	23	3.7385	0.632456
36	33.5	0.025	27	3.7385	0.707107
36.5	33	0.035	31	3.7385	0.83666
39	37	0.02	35	3.7385	0.632456
38.5	37.5	0.01	39	3.7385	0.447214
38	37.5	0.005	39.5	3.7385	0.316228
38.5	38	0.005	42	3.7385	0.316228

Table.12 Calculation of Velocity for 4.4cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/1000**	**X AXIS**	**Y AXIS**	**VELOCITY $(2*gh)^{½}$,(m/s)**
14	12	0.02	6.5	1.2385	0.632456
15	14	0.01	7	1.2385	0.447214
13	12	0.01	11	1.2385	0.447214

12	10	0.02	15	1.2385	0.632456
11.5	10	0.015	19	1.2385	0.547723
12.5	9	0.035	23	1.2385	0.83666
11	9	0.02	27	1.2385	0.632456
13.5	11	0.025	31	1.2385	0.707107
13.5	12	0.015	35	1.2385	0.547723
13	11.5	0.015	39	1.2385	0.547723
12.5	11.5	0.01	39.5	1.2385	0.447214
10	8	0.02	4.76	2.9785	0.632456
9.5	6	0.035	6.5	2.9785	0.83666
11	8	0.03	7	2.9785	0.774597
13.5	7.5	0.06	11	2.9785	1.095445
12.5	7.5	0.05	15	2.9785	1
12.5	8	0.045	19	2.9785	0.948683
11.5	8	0.035	23	2.9785	0.83666
12	9	0.03	27	2.9785	0.774597
14	11	0.03	31	2.9785	0.774597
14.5	12	0.025	35	2.9785	0.707107
14	11.5	0.025	39	2.9785	0.707107
14.5	12	0.025	39.5	2.9785	0.707107
12.5	11.5	0.01	41.24	2.9785	0.447214
9	7.5	0.015	3.86	3.8785	0.547723
9	6	0.03	6.5	3.8785	0.774597
9.5	6	0.035	7	3.8785	0.83666
13	7	0.06	11	3.8785	1.095445
12	6.5	0.055	15	3.8785	1.048809
11.5	7	0.045	19	3.8785	0.948683
11	7	0.04	23	3.8785	0.894427
12.5	10.5	0.02	27	3.8785	0.632456
10.5	8	0.025	31	3.8785	0.707107
13	11.5	0.015	35	3.8785	0.547723
13	11	0.02	39	3.8785	0.632456

13	10	0.03	39.5	3.8785	0.774597
13.5	13	0.005	42.14	3.8785	0.316228
10	9	0.01	3.18	4.5785	0.447214
10	7	0.03	6.5	4.5785	0.774597
10	4	0.06	7	4.5785	1.095445
14	3	0.11	11	4.5785	1.48324
11.5	6.5	0.05	15	4.5785	1
12.5	7.5	0.05	19	4.5785	1
11	5	0.06	23	4.5785	1.095445
11.5	8.5	0.03	27	4.5785	0.774597
11	8	0.03	31	4.5785	0.774597
9	7.5	0.015	35	4.5785	0.547723
14	9	0.05	39	4.5785	1
14	10	0.04	39.5	4.5785	0.894427
15	14.5	0.005	42.82	4.5785	0.316228

Table.13 Calculation of Velocity for 5cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/100**	**X AXIS**	**Y AXIS**	**VELOCITY $(2*gh)^{½}$,(m/s)**
13.5	10.5	0.03	6.5	1.2385	0.774597
14.5	11	0.035	7	1.2385	0.83666
14	8	0.06	11	1.2385	1.095445
17	14	0.03	15	1.2385	0.774597
17	14	0.03	19	1.2385	0.774597
17	14	0.03	23	1.2385	0.774597
17	14	0.03	27	1.2385	0.774597
20	17	0.03	31	1.2385	0.774597
19.5	17.5	0.02	35	1.2385	0.632456
20	17.5	0.025	39	1.2385	0.707107
19	16.5	0.025	39.5	1.2385	0.707107

13.5	10	0.035	5.5	2.2385	0.83666
13.5	10	0.035	6.5	2.2385	0.83666
13.5	10	0.035	7	2.2385	0.83666
12.5	8	0.045	11	2.2385	0.948683
16	11.5	0.045	15	2.2385	0.948683
16	11.5	0.045	19	2.2385	0.948683
16	11	0.05	23	2.2385	1
16	11.5	0.045	27	2.2385	0.948683
19	15	0.04	31	2.2385	0.894427
19	15.5	0.035	35	2.2385	0.83666
19.5	16	0.035	39	2.2385	0.83666
19.5	16	0.035	39.5	2.2385	0.83666
18.5	17.5	0.01	40.5	2.2385	0.447214
13.5	10.5	0.03	4.5	3.2385	0.774597
19	15	0.04	6.5	3.2385	0.894427
19	14.5	0.045	7	3.2385	0.948683
18	12	0.06	11	3.2385	1.095445
16	11	0.05	15	3.2385	1
16	10.5	0.055	19	3.2385	1.048809
16	10.5	0.055	23	3.2385	1.048809
16	11	0.05	27	3.2385	1
19.5	14.5	0.05	31	3.2385	1
19	15	0.04	35	3.2385	0.894427
19	15.5	0.035	39	3.2385	0.83666
19	15.5	0.035	39.5	3.2385	0.83666
19	18	0.01	41.5	3.2385	0.447214
13	10.5	0.025	3.5	4.2385	0.707107
12.5	8	0.045	6.5	4.2385	0.948683
13	8	0.05	7	4.2385	1
17	10.5	0.065	11	4.2385	1.140175
15.5	9	0.065	15	4.2385	1.140175
16	9	0.07	19	4.2385	1.183216

15	9.5	0.055	23	4.2385	1.048809
15	10	0.05	27	4.2385	1
18.5	13.5	0.05	31	4.2385	1
14.5	8.5	0.06	35	4.2385	1.095445
18.5	15	0.035	39	4.2385	0.83666
18.5	15	0.035	39.5	4.2385	0.83666
19	18	0.01	42.5	4.2385	0.447214
13.5	10	0.035	2.5	5.2385	0.83666
13.5	9	0.045	6.5	5.2385	0.83666
13	8	0.05	7	5.2385	0.948683
17	11	0.06	11	5.2385	1
16	9	0.07	15	5.2385	1.095445
16	10.5	0.055	19	5.2385	1.183216
15	10.5	0.045	23	5.2385	1.048809
16	11	0.05	27	5.2385	0.948683
18.5	15	0.035	31	5.2385	1
19	15.5	0.035	35	5.2385	0.83666
18.5	16.5	0.02	39	5.2385	0.83666
18.5	16.5	0.02	39.5	5.2385	0.632456
17	16	0.01	43.5	5.2385	0.632456

Table.14 Calculation of Velocity for 5.5cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/1000**	**X AXIS**	**Y AXIS**	**VELOCITY $(2*gh)^{½}$,(m/s)**
7	4.5	0.025	6.5	1.2385	0.707107
8.5	4	0.045	7	1.2385	0.948683
6.5	3	0.035	11	1.2385	0.83666
6.5	3.5	0.03	15	1.2385	0.774597
7	3	0.04	19	1.2385	0.894427

7	4	0.03	23	1.2385	0.774597
7	3.5	0.035	27	1.2385	0.83666
4.5	1	0.035	31	1.2385	0.83666
4.5	0	0.045	35	1.2385	0.948683
3.5	0.5	0.03	39	1.2385	0.774597
3.5	1	0.025	39.5	1.2385	0.707107
7	4	0.03	4.76	2.9785	0.774597
9	4	0.05	6.5	2.9785	1
9.5	4	0.055	7	2.9785	1.048809
6.5	0	0.065	11	2.9785	1.140175
9	3	0.06	15	2.9785	1.095445
9	3	0.06	19	2.9785	1.095445
9	4	0.05	23	2.9785	1
9	4	0.05	27	2.9785	1
6	0	0.06	31	2.9785	1.095445
6	1	0.05	35	2.9785	1
4.5	1	0.035	39	2.9785	0.83666
4	1	0.03	39.5	2.9785	0.774597
3.5	1	0.025	41.24	2.9785	0.707107
7.5	5	0.025	3.02	4.7185	0.707107
9	4	0.05	6.5	4.7185	1
9.5	4	0.055	7	4.7185	1.048809
8.5	1	0.075	11	4.7185	1.224745
8.5	3	0.055	15	4.7185	1.048809
9	3	0.06	19	4.7185	1.095445
8.5	3.5	0.05	23	4.7185	1
8.5	3	0.055	27	4.7185	1.048809
5.5	0	0.055	31	4.7185	1.048809
4.5	0	0.045	35	4.7185	0.948683
5.5	1	0.045	39	4.7185	0.948683
5	1	0.04	39.5	4.7185	0.894427
3.5	1	0.025	42.98	6.4585	0.707107

8.5	5	0.035	1.28	6.4585	0.83666
10	5.5	0.045	6.5	6.4585	0.948683
10.5	5.5	0.05	7	6.4585	1
9	2	0.07	11	6.4585	1.183216
10.5	4	0.065	15	6.4585	1.140175
10.5	3	0.075	19	6.4585	1.224745
10	4	0.06	23	6.4585	1.095445
9.5	4	0.055	27	6.4585	1.048809
5.5	1	0.045	31	6.4585	0.948683
5	0	0.05	35	6.4585	1
5	0.5	0.045	39	6.4585	0.948683
5.5	0.5	0.05	39.5	6.4585	1
1.5	0	0.015	44.72	6.4585	0.547723

Table.15 Calculation of Velocity for 7.28cm Depth of Flow

DYNAMIC PRESSURE (D)	**STATIC PRESSURE (S)**	**DIFFERENCE (S-D)/1000**	**X AXIS**	**Y AXIS**	**VELOCITY $(2*gh)^{½}$,(m/s)**
21.5	19.5	0.02	**6.5**	1.2385	0.632456
21	20.5	0.005	7	1.2385	0.316228
18	17	0.01	11	1.2385	0.447214
19	18	0.01	15	1.2385	0.447214
19	18	0.01	19	1.2385	0.447214
17.5	16.5	0.01	23	1.2385	0.447214
18.5	17	0.015	27	1.2385	0.547723
16.5	15	0.015	31	1.2385	0.547723
21	18	0.03	35	1.2385	0.774597
20.5	18	0.025	39	1.2385	0.707107
20.5	18	0.025	39.5	1.2385	0.707107
21	19	0.02	4.3	3.4385	0.632456
21	20	0.01	6.5	3.4385	0.447214

21	17.5	0.035	7	3.4385	0.83666
18.5	14.5	0.04	11	3.4385	0.894427
19.5	16	0.035	15	3.4385	0.83666
19.5	17	0.025	19	3.4385	0.707107
19	16	0.03	23	3.4385	0.774597
18.5	16.5	0.02	27	3.4385	0.632456
16	13	0.03	31	3.4385	0.774597
15.5	13	0.025	35	3.4385	0.707107
16	13.5	0.025	39	3.4385	0.707107
16	13.5	0.025	39.5	3.4385	0.707107
16	14.5	0.015	41.7	3.4385	0.547723
21.5	20	0.015	2.85	4.885	0.547723
21	19	0.02	6.5	4.885	0.632456
21	18	0.03	7	4.885	0.774597
18	14	0.04	11	4.885	0.894427
18	15	0.03	15	4.885	0.774597
18.5	15	0.035	19	4.885	0.83666
18	14	0.04	23	4.885	0.894427
18	14	0.04	27	4.885	0.894427
18	13.5	0.045	31	4.885	0.948683
16.5	13.5	0.03	35	4.885	0.774597
16.5	14	0.025	39	4.885	0.707107
16.5	14	0.025	39.5	4.885	0.707107
16	14	0.02	43.15	4.885	0.632456
21	18.5	0.025	1.4	6.3385	0.632456
22	19	0.03	6.5	6.3385	0.83666
22	19	0.03	7	6.3385	0.83666
18.5	15	0.035	11	6.3385	1.048809
19	15	0.04	15	6.3385	1.095445
18.5	14	0.045	19	6.3385	1.048809
18.5	14	0.045	23	6.3385	0.948683
18.5	15	0.035	27	6.3385	0.707107

16.5	14	0.025	31	6.3385	0.774597
17	14	0.03	35	6.3385	0.447214
17	14	0.03	39	6.3385	0.447214
16.5	14	0.025	39.5	6.3385	0.447214
16.5	14.5	0.02	44.6	6.3385	0.316228
16.5	14.5	0.02	0	7.7385	0.632456
21.5	18	0.035	6.5	7.7385	0.83666
21.5	18	0.035	7	7.7385	0.83666
18.5	13	0.055	11	7.7385	1.048809
19	13	0.06	15	7.7385	1.095445
18.5	13	0.055	19	7.7385	1.048809
18.5	14	0.045	23	7.7385	0.948683
17.5	15	0.025	27	7.7385	0.707107
16	13	0.03	31	7.7385	0.774597
15	14	0.01	35	7.7385	0.447214
14.5	13.5	0.01	39	7.7385	0.447214
14.5	13.5	0.01	39.5	7.7385	0.447214
14	13.5	0.005	46	7.7385	0.316228
16.5	11.5	0.05	0	6.5	1
16.5	11.5	0.05	-8	6.5	1
16	11	0.05	0	7	1
21	15	0.055	-8	7	1.0488
22	21	0.01	46	6.5	0.4472
22	21	0.01	54	6.5	0.4472
18.5	17.5	0.01	46	7	0.4472
19	18	0.01	54	7	0.4472

Table.16 Calculation of Velocity for 8.04cm Depth of Flow

DYNAMIC PRESSURE (D)	STATIC PRESSURE (S)	DIFFERENCE (S-D)/1000	X AXIS	Y AXIS	VELOCITY $(2*gh)^{½}$,(m/s)
13	12.5	0.005	6.5	1.2385	0.316228
13.5	13	0.005	7	1.2385	0.316228
9	8	0.01	11	1.2385	0.447214
11	10	0.01	15	1.2385	0.447214
11	10	0.01	19	1.2385	0.447214
11.5	11	0.005	23	1.2385	0.316228
10.5	10	0.005	27	1.2385	0.316228
9	8	0.01	31	1.2385	0.447214
9	8	0.01	35	1.2385	0.447214
9.5	9	0.005	39	1.2385	0.316228
9	8	0.01	39.5	1.2385	0.447214
16	15	0.01	4.3	2.8385	0.447214
10	9.5	0.005	6.5	2.8385	0.316228
13.5	11.5	0.02	7	2.8385	0.632456
9.5	8	0.015	11	2.8385	0.547723
11.5	10	0.015	15	2.8385	0.547723
13.5	12	0.015	19	2.8385	0.547723
11.5	10.5	0.01	23	2.8385	0.447214
13	11	0.02	27	2.8385	0.632456
8.5	6	0.025	31	2.8385	0.707107
12	11	0.01	35	2.8385	0.447214
12	10.5	0.015	39	2.8385	0.547723
12	10	0.02	39.5	2.8385	0.632456
12.5	11.5	0.01	41.7	2.8385	0.447214
12	11	0.01	2.85	5.2385	0.447214
12.5	11	0.015	6.5	5.2385	0.547723
12.5	10.5	0.02	7	5.2385	0.632456
9	7	0.02	11	5.2385	0.632456

11	9	0.02	15	5.2385	0.632456
11	9	0.02	19	5.2385	0.632456
10.5	9	0.015	23	5.2385	0.547723
11	9	0.02	27	5.2385	0.632456
8	6	0.02	31	5.2385	0.632456
8.5	6	0.025	35	5.2385	0.707107
12.5	10	0.025	39	5.2385	0.707107
11.5	10.5	0.01	39.5	5.2385	0.447214
11	10.5	0.005	43.15	5.2385	0.316228
13.5	12	0.015	1.4	6.0385	0.547723
10.5	9.5	0.01	6.5	6.0385	0.447214
13.5	11	0.025	7	6.0385	0.707107
8.5	5	0.035	11	6.0385	0.83666
10.5	7	0.035	15	6.0385	0.83666
12	8	0.04	19	6.0385	0.894427
10.5	7	0.035	23	6.0385	0.83666
12	9	0.03	27	6.0385	0.774597
7.5	5	0.025	31	6.0385	0.707107
9.5	8.5	0.01	35	6.0385	0.447214
10	8	0.02	39	6.0385	0.632456
10	9.5	0.005	39.5	6.0385	0.316228
11	10	0.01	44.6	6.0385	0.447214
12	11.5	0.005	0	8.0385	0.316228
12	11	0.01	6.5	8.0385	0.447214
12	10	0.02	7	8.0385	0.632456
7.5	4	0.035	11	8.0385	0.83666
9	5	0.04	15	8.0385	0.894427
9	4	0.05	19	8.0385	1
9	5	0.04	23	8.0385	0.894427
8.5	4	0.045	27	8.0385	0.948683
6	2	0.04	31	8.0385	0.894427
6	1	0.05	35	8.0385	1

6.5	2	0.045	39	8.0385	0.948683
6.5	5	0.015	39.5	8.0385	0.547723
6.5	6	0.005	46	8.0385	0.316228
7.5	4	0.035	0	7.5	0.83666
8.5	4	0.045	-4	7.5	0.948683
10.5	9.5	0.01	46	7.5	0.4472
10.5	9.5	0.01	50	7.5	0.4472

CHAPTER-4

RESULTS AND DISCUSSION

4.1**Velocity Contour and Graph**

The velocity distribution is measured with the help of Pitot-tube as mentioned above. Velocity distribution in open channel flow depends on various factors such as channel cross-section, roughness, depth of flow and the presence of bends in the channel alignment. This instrument is used to record the pressure difference along the flow of rver. This difference in the pressure used to calculate the velocity by using formula [2];

$$V= (2gh)^{1/2} \qquad \text{- - -(4.1)}$$

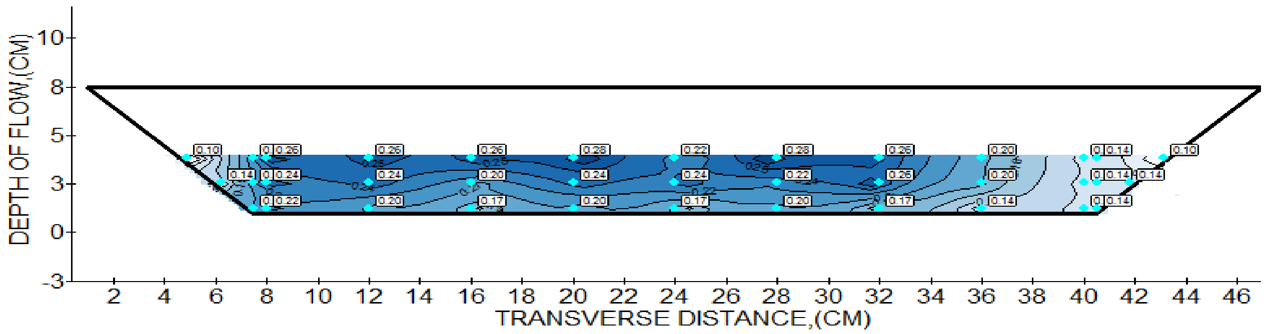
To analyse the velocity distribution in the cross-over section of flow it was necessary to draw velocity contour. Velocity contour are made with help of 3-D field. 3DField is a contouring surface plotting and 3D data program. 3DField converts the data into contour maps and surface plots. It creates a 3D map or a contour chart from the scattered points, numerical arrays or other data set. All aspects of 2D or 3D maps can be customized to produce exactly the presentation.

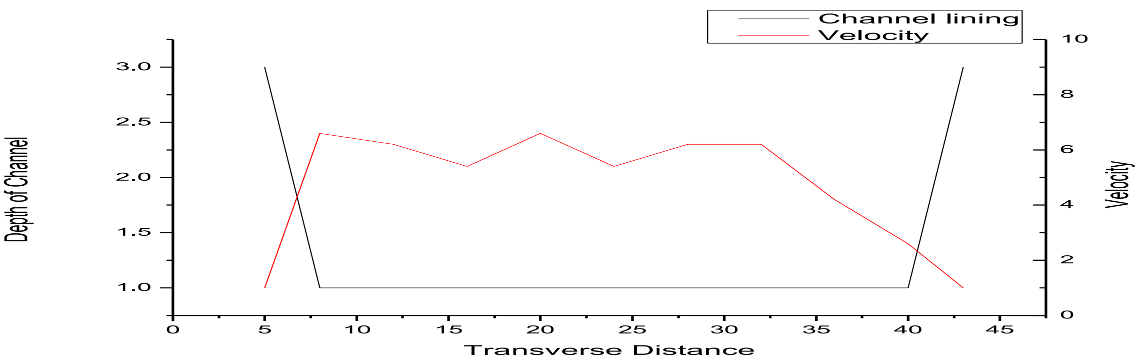
Graphs between velocity vs transverse distance and transverse distance vs depth of flow was drawn with the help of software origin. With the Plot Setup dialog, graphs can be easily plotted.

Graphs and contours where drawn for different sinusoidal meandering trapezoidal channels.

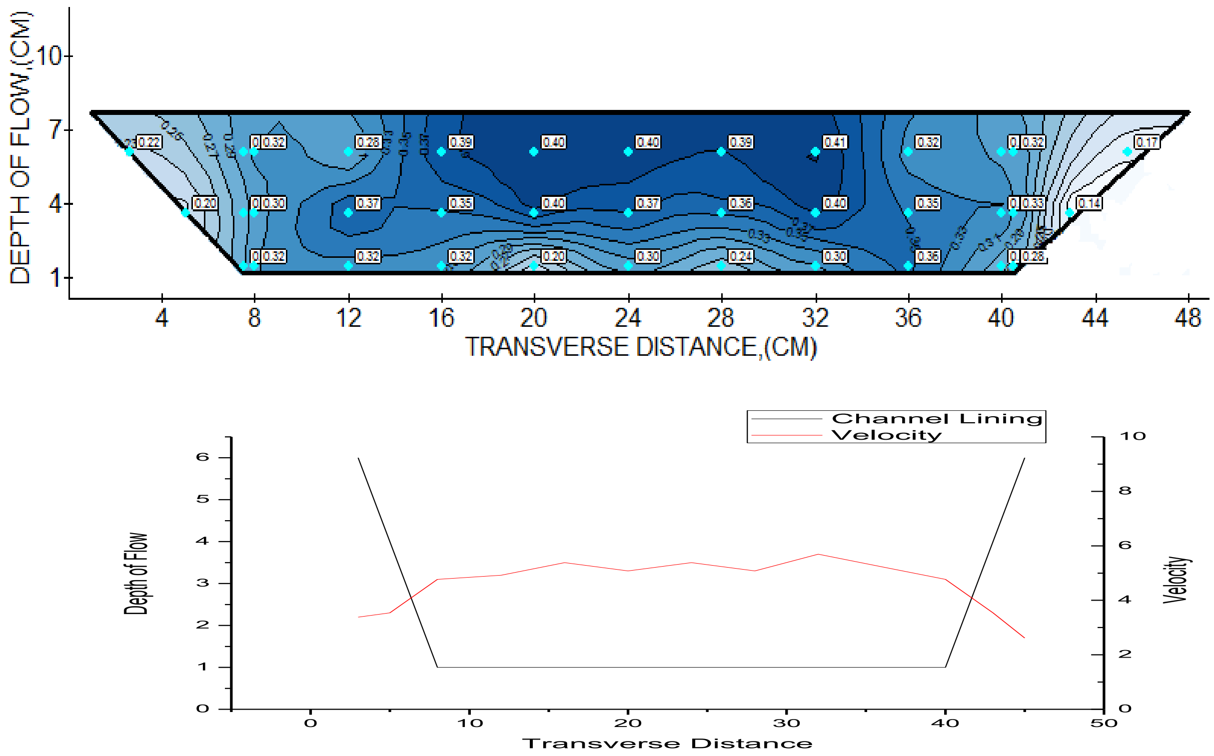
Fig.5 (a) and (b) is the depth averaged velocity graph and distribution of tangential velocity in contour form for the runs of meandering channels for in bank flow at cross-over. Similarly Fig.5 (c),(d) and (e) depth averaged graph and velocity distribution contour for meandering channel of sinuosity 1.25. Fig.6 (a),(b),(c),(d) and (e) shows the velocity distribution contour and depth average velocity graph for in bank flow of a channel of sinuosity 1.5.

The velocity of flow in the open channel flow is not uniform everywhere. The non-uniform flow is due to friction and other factors. The velocity measured along the channel is always varied because of boundary shear. Velocity profile is not symmetric as that in the pipe flow[3]. The velocity is expected to be maximum at the flow surface where shear force is zero but that is not the case. The velocity is found to be maximum at the top just below the surface flow [3].

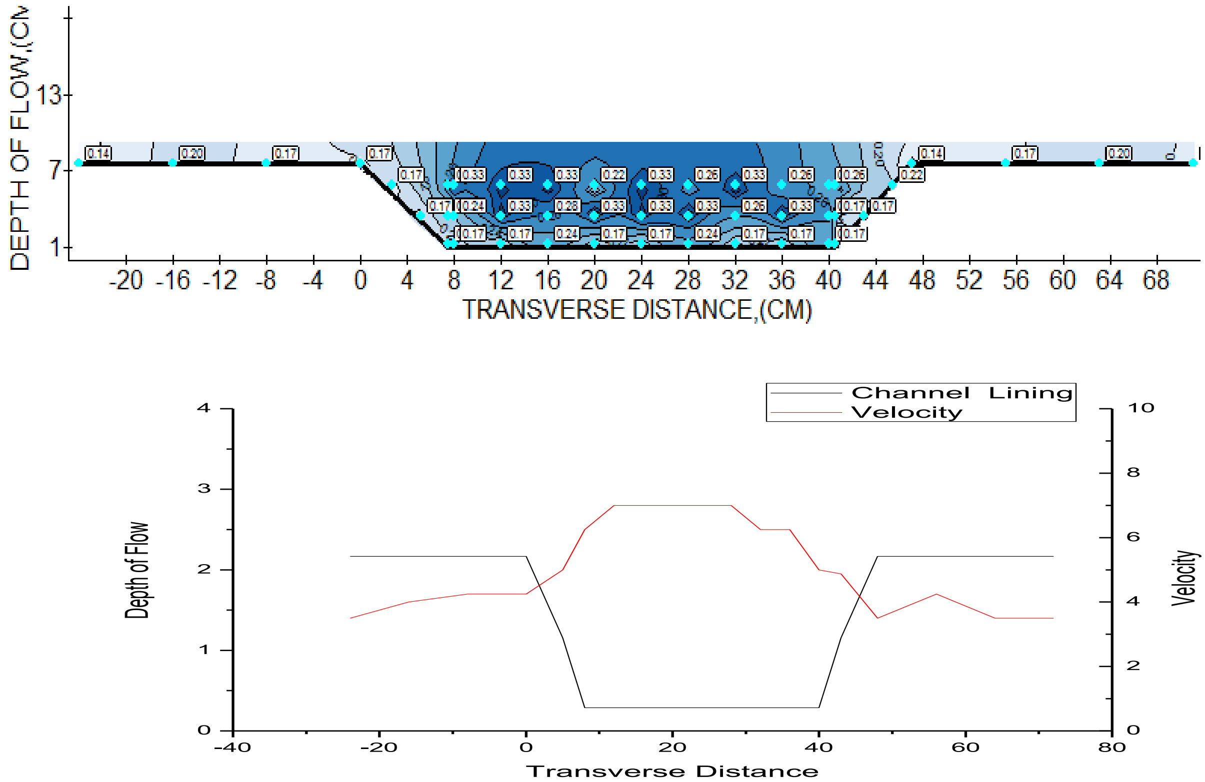




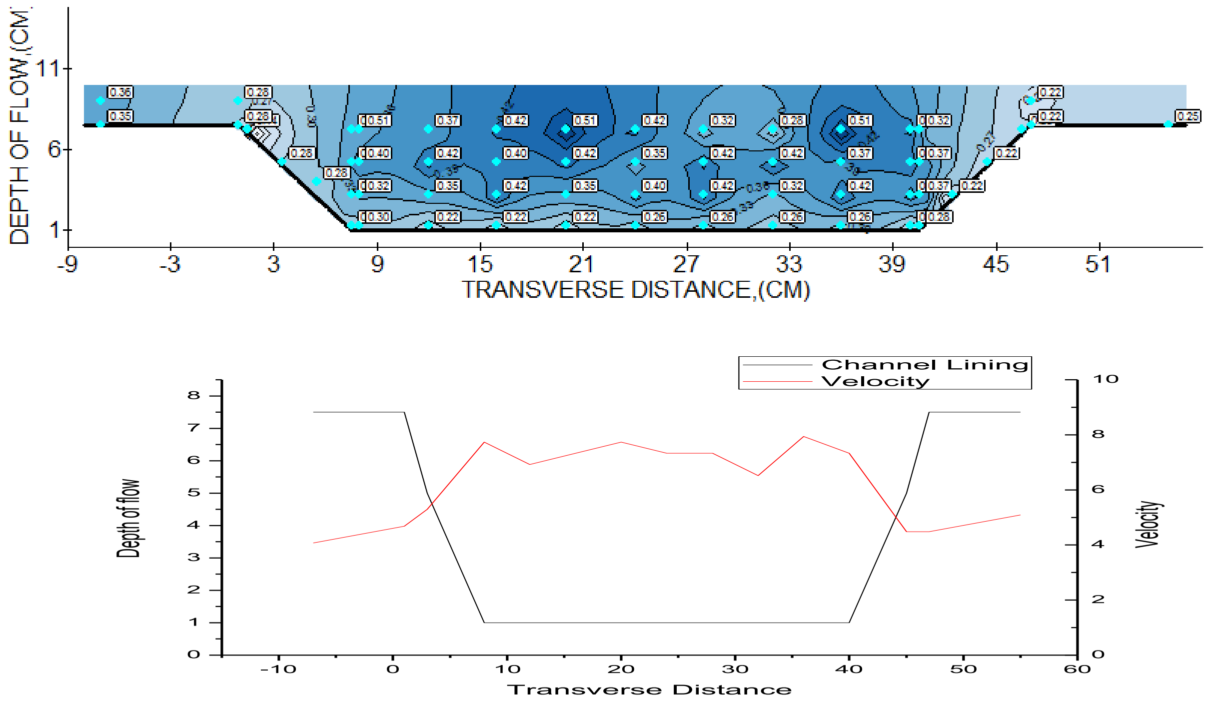
(a) In bank flow for 3.27cm depth



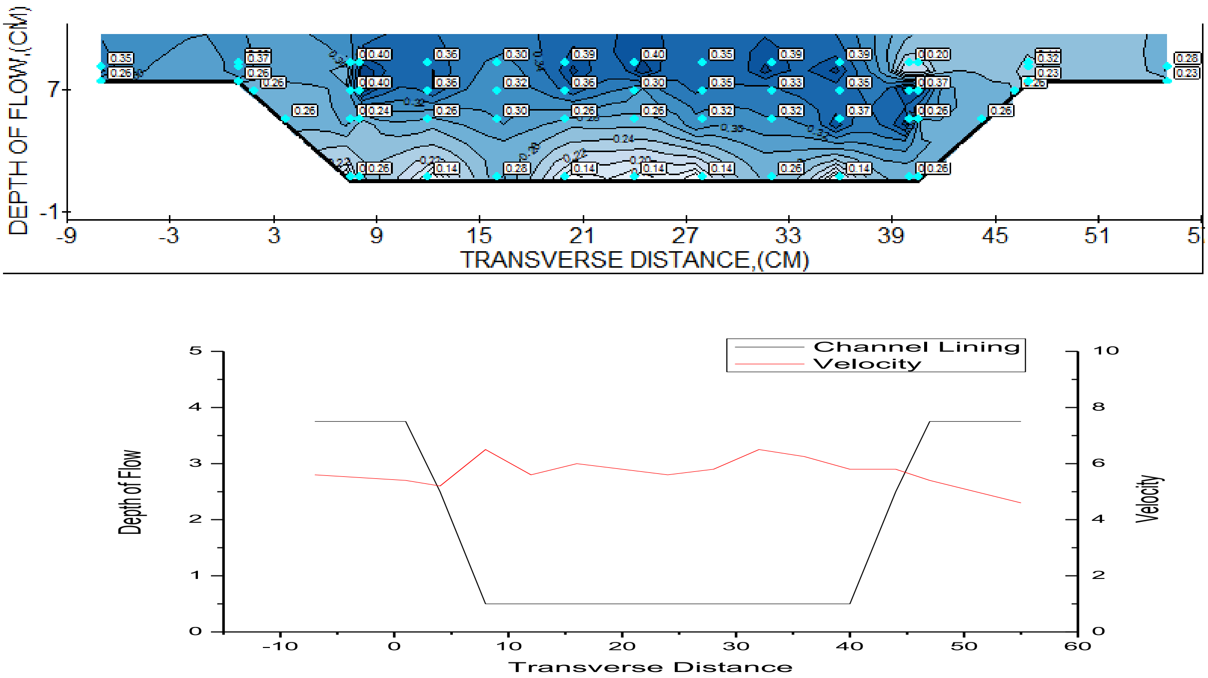
(b) In bank flow for 6.08cm depth



(c) Over bank flow for 8.265cm depth

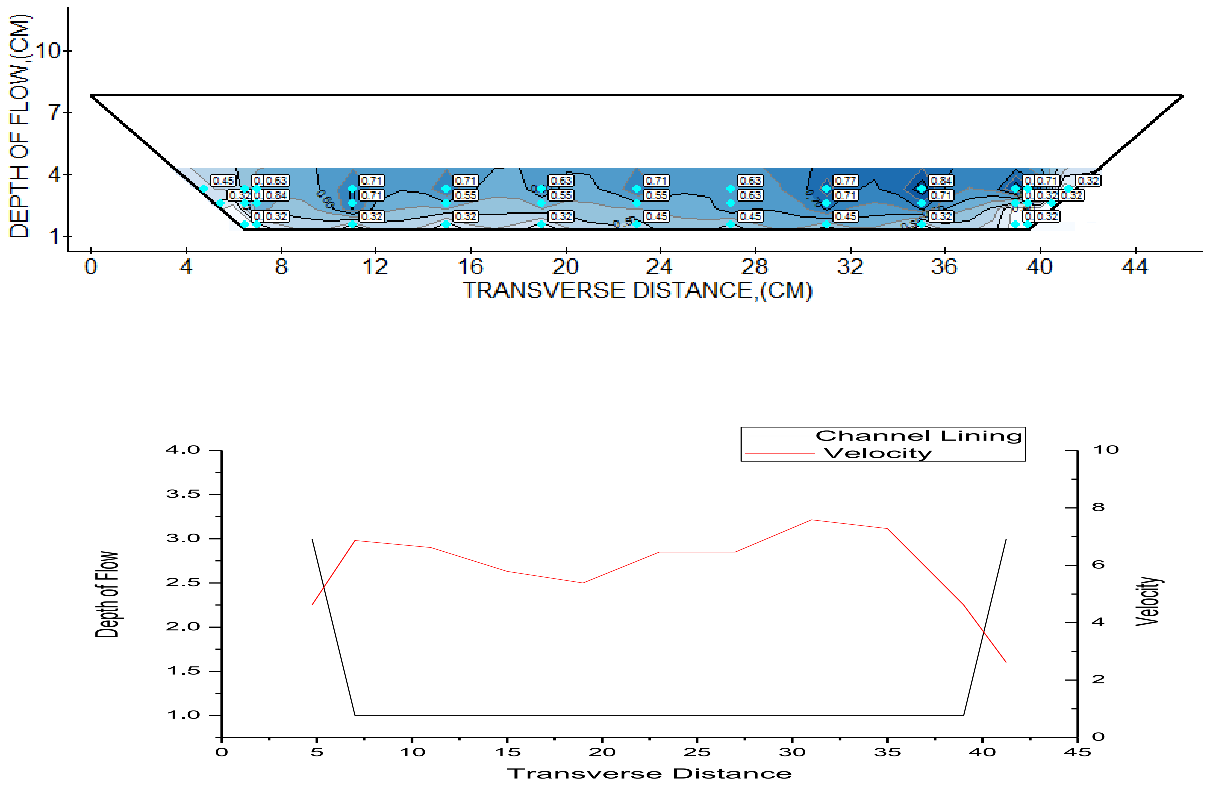


(d) Over bank flow for 9.9 cm depth

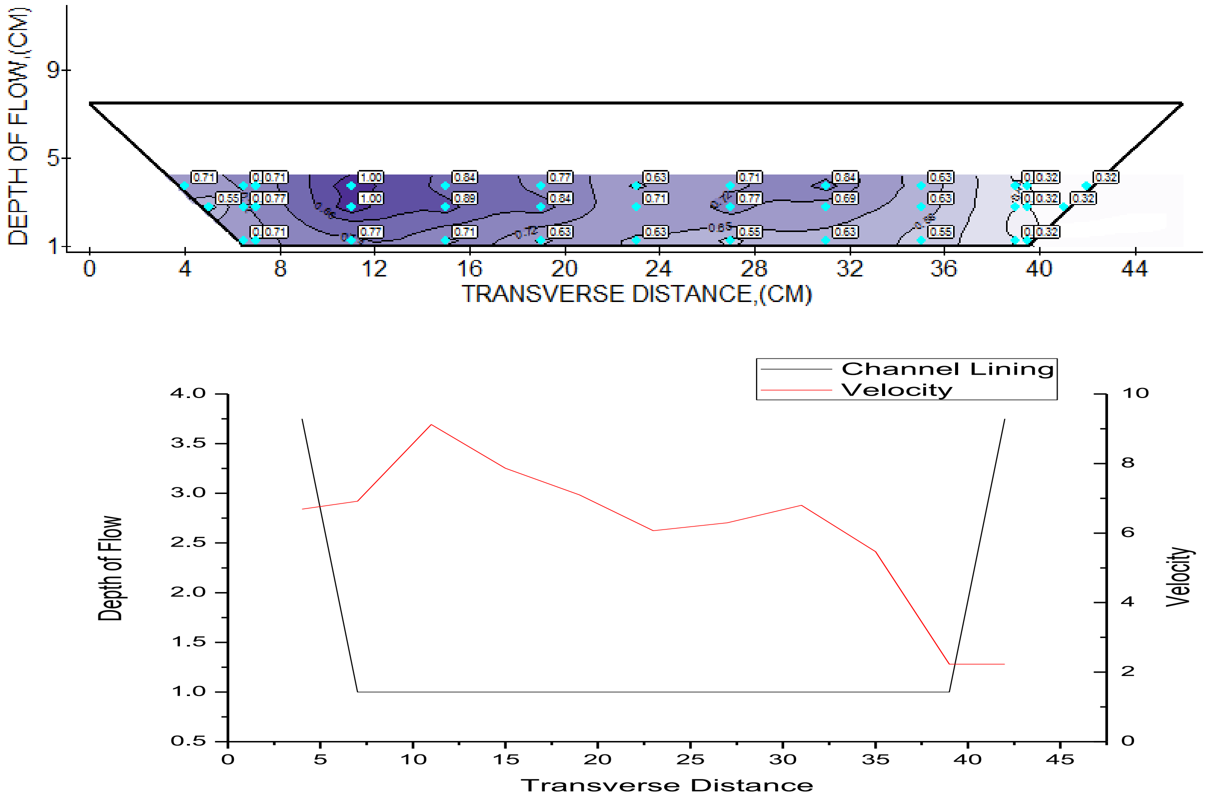


(e) In bank flow for 3.27cm depth

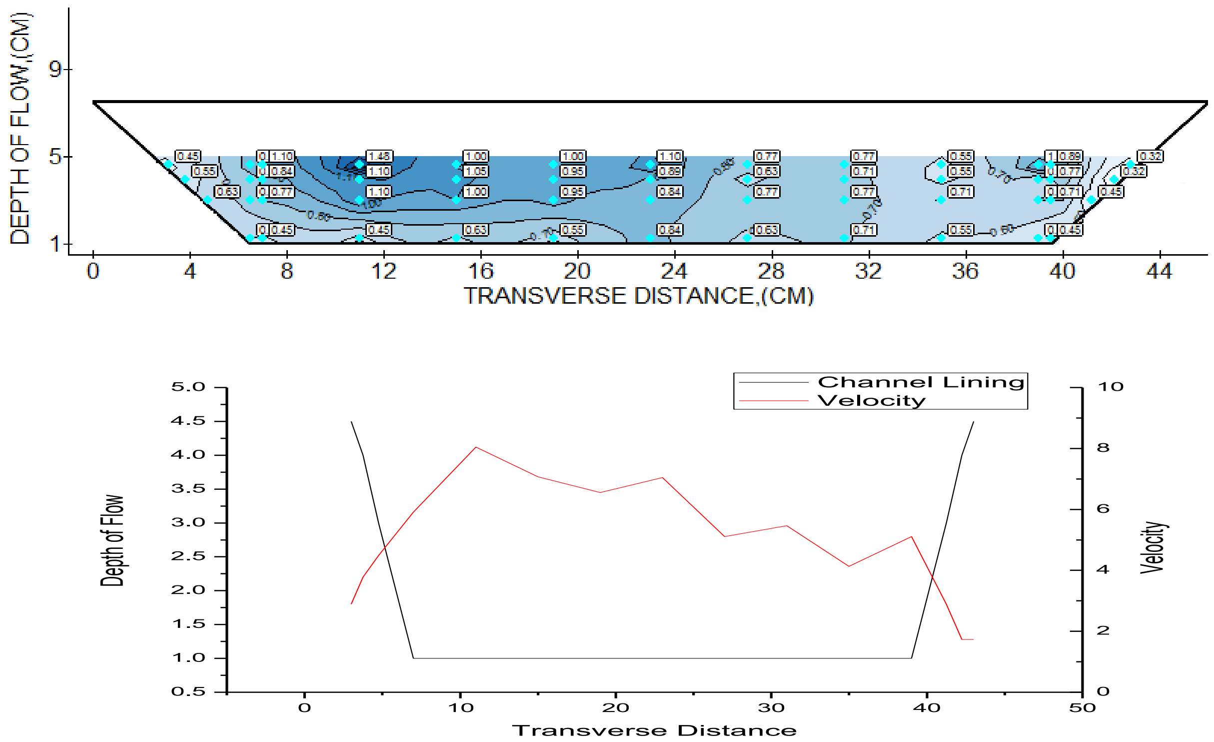
Fig.5 Velocity contour and graph for different flow in the cross-over of a trapezoidal meandering channel of sinuosity 1.25



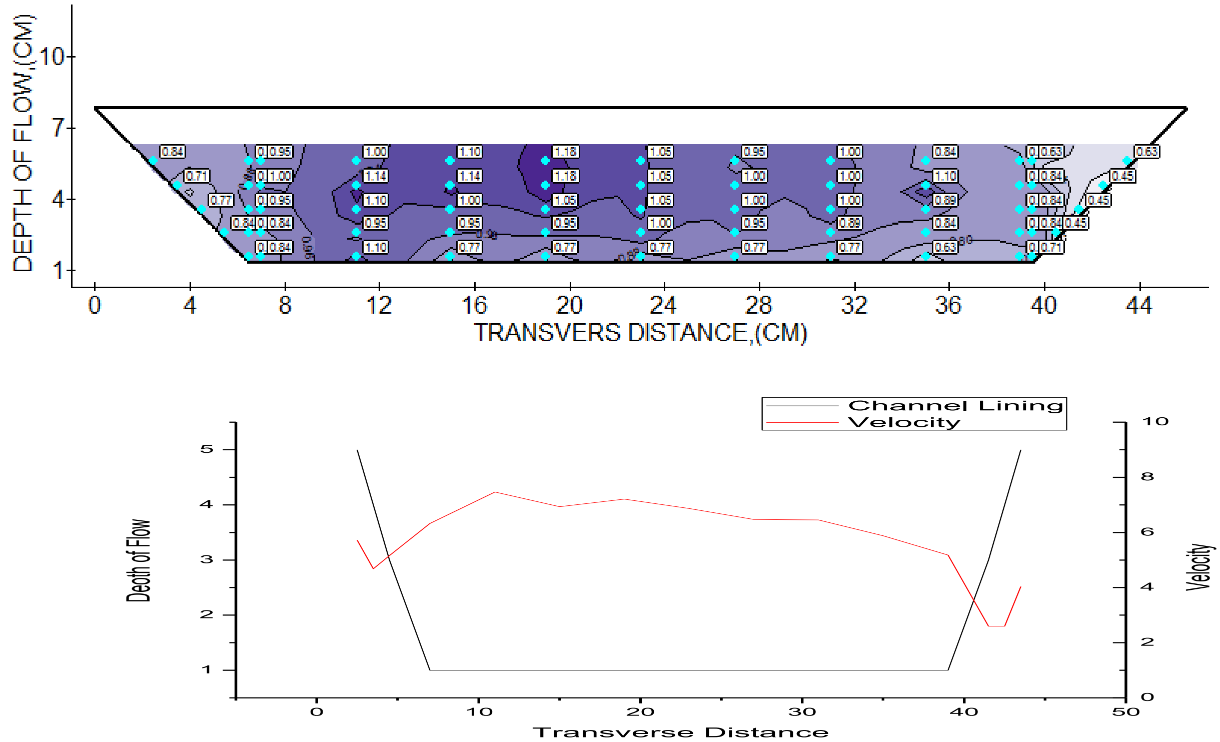
(a) In bank flow for 2.8cm depth



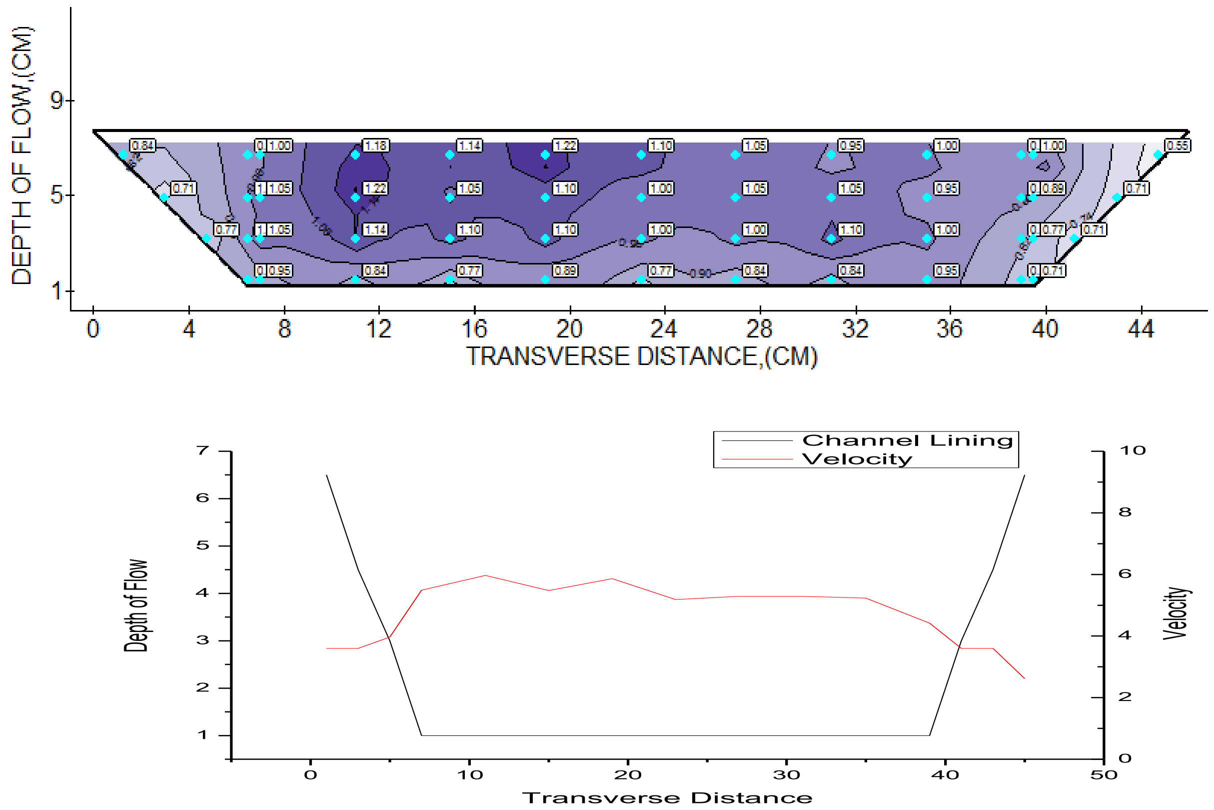
(b) In bank flow for 3.28cm depth



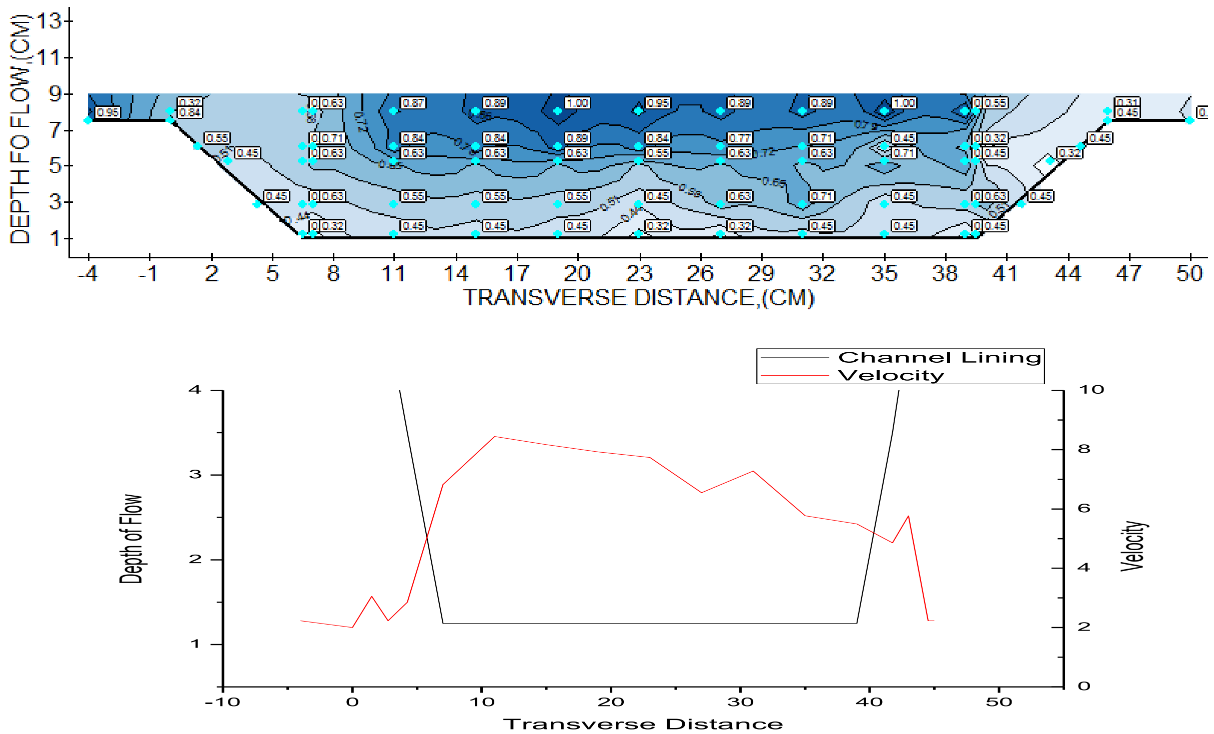
(c) In bank flow for 4.4cm depth



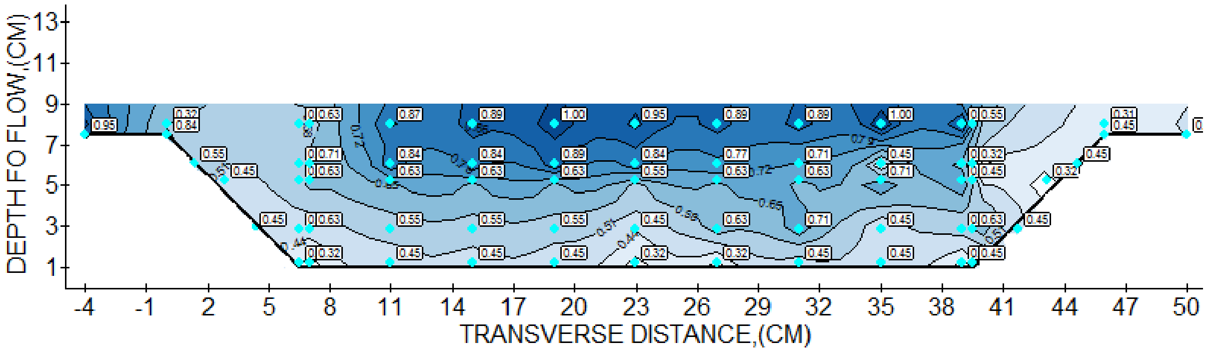
(d) In bank flow for 5cm depth



(e) In bank flow for 5cm depth



(f) Over bank flow for 7.28cm depth



(g) Over bank flow for 8.04cm depth

Fig.6 Velocity contour and graph for different flow in the cross-over of a trapezoidal meandering channel of sinuosity 1.5

Chapter-5
Conclusion

(1) The contour of velocity distribution indicates the maximum velocity at the middle of the channel. Graph and contour shows the maximum velocity at the middle of the cross-over of meandering channel looking around the downstream. Due to maximum velocity at the middle reach of the cross over.

(2) Maximum velocity of two consecutive inner bank is the main reason of concentration velocity at middle reach of cross-over as observed by the contour and graphs.

(3) Due to flow channel lining results thread. Thread is less in both side of the wall as the velocity in the bend apex from inner side of the wall is sifted to centre. Found in the investigation o Kar (1977), Bhattacharya (1995), and Patra and Kar (2004),they conducted their experiment in the deep, strongly meandering channels with rigid boundary.

(4) Velocity distribution in the compound channel is similar to that of the simple channel. There is sudden change in velocity at the channel flood-plain junction this is because of rapid varied flow (R.V.F)[2].

(5) Comparing the inner channel flood-plain junction with outer velocity contour shows slightly more velocity at the inner junction confirming the findings of Kar (1977), Bhattacharya (1995), and Patra and Kar (2004).

(6) From the velocity contour and graph it was observed that as the depth of flow increases the flow velocity also increases for simple meandering channel.

(7) For the compound meandering channel it was observed that when over flows in the flood plain the mean velocity of section reduces. Mean velocity at section is found to be less than the main channel as the depth of flow increases the mean velocity at flood plain also increases[1].

REFERENCES

1. Khatua K.K, Interaction of Flow and Estimation of Discharge in two Stage Meandering Compound Channels, Department of Civil Engineering, N.I.T. Rourkela, Orissa, India.
2. Bansak R.K., Fluid Mechanics and Hydralic machines,Laxmi publication
3. Boxall J.B., Guymer I., Longitudinal mixing in meandering channels: New experimental data set and verification of a predictive technique, WATER RESEARCH 41 (2007) 341– 354
4. Kyle M.Straub, David Mohring, Quantifying the influence of channel sinuosity on the depositional mechanics of channelized turbidity currents: A laboratory study,Marine and Petroleum Geology, 28 (2011) 744-760
5. Blanckaert K., Duarte A., Schleiss A.J., Influence of shallowness, bank inclination and bank roughness on the variability of flow patterns and boundary shear stress due to secondary currents in straight open-channels,Advances in Water Resources 33(2010) 1062-1074
6. Jeff Peakall, Gupta Sanjeev, Bradbury P.William **,(**2006) Flow processes and sedimentation in submarine channel bends,Marine and Petroleum Geology, 24 (2007) 470-486
7. Jha. Ramakar (Scientist E1), surface water quality modelling , National institute of Hydology Roorkee, Surface Water Quality Modelling
8. Kumar C.P. (Scientist F), Fresh Water Resources: A Perspective, National institute of Hydology Roorkee
9. Kövári J., United Nations Development Programme Food and Agriculture Organization of the United Nations(1984) Rome, Italy, ADCP/REP/84/21 - Inland Aquaculture Engineering
10. Khatua K.K.and Patra K.C.**,** Boundary shear stress distribution in meandering compound channel flow, Department of civil engineering Nit Rourkela, Orissa, India
11. Donald w.Knight, Mazen Omran, and Xiaonan Tang, Modeling Depth-Averaged Velocity and Boundary Shear in Trapezoidal Channels with Secondary Flows, JOURNAL OF HYDRALLIC ENGINEERING ASCE/ JAN /133,39(2007)
12. Patra,K.C. (1999)). Flow interaction of Meandering River with Flood plains, PhD Thesis, Indian Institute ofTechnology, Kharagpur.

13. Patra, K. C. & Kar, S.K.(2000). Flow interaction of meandering river with floodplains. Jr of Hydr. Engg. 126, 8,593-603
14. Knight, D.W. & Demetriou, J.D. (1983). Floodplain and Main Channel Flow Interaction. Jr of Hyd. Engrg. ASCE 109, No.8, 1073-1092.
15. Knight, D.W. & Hamed, M.E (1984). Boundary Shear in Symmetrical Compound Channels. Jr of Hyd. Engrg,ASCE 110, No.10:1412-1430.
16. Part 654 - Stream Restoration Design, united states nation agriculture,NRCS
17. Yee-Chung Jin, Zheng Y, Zarrati AR, Boundary shear distribution in straight ducts and open channels, JOURNAL OF HYDRALLIC ENGINEERING ASCE/ 924-928/ SEP/ (2004)